Addendum

1. METHOD FOR MEASURING DIMENSIONS AND ALIGNMENT OF THIN FILM MAGNETIC HEAD AND APPARATUS THEREFOR

Title of The Invention

METHOD FOR MEASURING DIMENSIONS AND ALIGNMENT OF THIN FILM MAGNETIC HEAD AND APPARATUS THEREFOR

Background of The Invention

The present invention relates to a method for measuring dimensions and alignment of a thin film magnetic head which comprises a magnetic induction type conversion element or a magnetoresistance effect element which is formed on a substrate by a lamination process, and a dimension and alignment measuring apparatus, more specifically relates to a method for measuring dimensions and alignment of the magnetoresistance effect element with a high degree of accuracy, and an apparatus for the same.

Lately, in magnetic disk apparatuses, there is the steady trend of reduction in size and enlargement in capacity and currently small size magnetic disk apparatuses equipped with a 3.5 inch or 2.5 inch disk are the mainstream. In such small size magnetic disk apparatuses, since the rotation speed of the disk is relatively low, decrease in reproduced output is a great concern regarding a magnetic induction type head whose reproduced output is dependent on the disk speed.

On the contrary to this, a magnetoresistance effect type head (hereinafter referred to as MR head: MR = magneto-resistive) that employs a magnetoresistance effect element (hereinafter referred to as MR element) whose resistance varies in accordance with the change of a magnetic field reproduces output that is not dependent on the speed of the disk, and hence can have high reproduced output even in the case of a small size magnetic disk apparatus.

Besides, since the MR heads can deliver higher reproduced output compared to magnetic induction type magnetic heads even when applied to narrower tracks, which is accompanied by a higher-density storage configuration, the MR heads are considered to be a suitable magnetic head for the trend toward miniaturization and mass storage in the magnetic media.

By the way, since an MR head detects the change of the resistance value caused by the change of the magnetic field, an MR head that uses an MR element exposed in a plane of a magnetic head slider opposing to the disk (hereinafter referred to floating surface) has larger reproduction efficiency. In such an MR head whose MR element is exposed in the floating plane thereof, part of the MR element is

processed (lapped and polished, hereinafter referred to only "lap" for simplicity) so as to expose in the floating plane in processing the floating plane. A dimension in a direction normal to the floating plane of the MR element is called the height of the MR element (h_{MR}), which is controlled so as to be within a prescribed value by controlling the amount of lapping in a lapping process.

In the MR head, the reproduced output changes depending on its height, and hence a problem that the reproduced output varies or the reproduced output cannot reach the prescribed level may occur if the heights of the MR elements vary.

Therefore, to prevent the variation in reproduced output of the MR head and also to attain a high yield, it is necessary to control the heights of the MR elements with a high degree of accuracy in the lapping process. For example, in the case of a surface recording density of 4 Gbit/inch^2, presumably the accuracy of the height of the MR element is required to be ± 0.2 μm or so; in the case of the surface recording density of 10 Gbit/inch^2, the accuracy is required to be ± 0.15 μm or so.

In order to control the heights of the MR elements with a high degree of accuracy in the lapping process, it is important to measure the heights of the MR elements accurately during the lapping. Presently, design height of the MR element is 0.5 to 3 μm or so. Since an induction type head for writing data is formed on a top of the MR element, it is difficult to measure directly the height of the MR element with optical means.

With this view, as Japanese Patent Laid-Open Publication Nos. 63-34713 and 2-29913, a method is proposed wherein the height of the MR element (or the amount of lapping in the lapping process) is measured indirectly by a method wherein a mensurative marker is formed in an element formation process and the marker is measured with optical means. However, this method can hardly be applied to in-process mensuration in the lapping process.

Now, a method is proposed as a feasible method to perform in-process mensuration wherein the resistance value of the MR element is measured and then the value is converted to the height of the MR element. This method can be implemented by two techniques: one is, as is described in Japanese Patent Laid-Open Publication No. 5-46945, to measure directly the resistance value of the MR element itself and convert the value to the height of the MR element; and the other is, as is described in Japanese Patent Laid-Open Publication No. 63-191570, to measure the

resistance of an element (hereinafter referred to as resistance detector element (ELG element; ELG= Electric Lapping Guide)) that is formed separately from the MR element and calculate the height of the MR element from the resistance value.

Of these methods, the former method for measuring directly the resistance of the MR element, the following problems have been pointed out.

(1) The MR element is formed using a thin film technology whose typical techniques are sputtering, exposure, ion-milling, etc. Dimensional accuracy attainable through this process is ± 0.2 μm or so. On the other hand, the width of the MR element (i.e. track width) is as narrow as 0.8 to 2.0 μm, and therefore the variation in the resistance value of the MR element occurs due to the variation in the track width.

(2) In forming an MR film by sputtering, there occurs the variation in its thickness depending its position in a wafer, namely a center part or an edge part, and the variation in the thickness in the wafer becomes a factor of the variation in the resistance value of individual MR elements. Especially in recent years, the film thickness of the MR element becomes thinner, and the unevenness of the film thickness tends to increase, and as a result the variation in the resistance value also increases.

That is, a real MR element suffers the variation in the resistance value due to the variation in the track width and the unevenness of the film thickness. This variation in the resistance value causes an error in measuring the height of the MR element, hence becoming one of factors responsible for deterioration of the accuracy of the measurement.

On the contrary to this, the latter method for performing in-process measurement by measuring the resistance value and converting the value to the height of the MR element has the following merits.

(1) In a resistance detector element, the track width can be larger (10 to 500 μm) arbitrarily, and therefore its resistance value hardly varies at all even when the track width varies by ± 0.2 μm or so. Therefore, the variation in the track width has only a little effect on the resistance value.

(2) In a resistance detector element, it is possible to cancel out the unevenness of the film thickness in calculating the height of the MR element form the resistance

value of the resistance detector element by the use of a reference pattern element (reference resistance).

As described in the foregoing, the method for performing mensuration of the height of the MR element by the use of the resistance detector element enables in-process mensuration of the height of the MR element with a high degree of accuracy because the effect of both the variation in the track width and the unevenness of the film thickness can be reduced. However, this method involves the following problems.

Both the resistance detector element and the MR element are formed by a thin film process whose typical techniques are sputtering, exposure, ion-milling, etc. In an exposure process, however, when there are the unevenness of a resist film thickness and the illuminance unevenness, there occurs the variation in exposure and hence the variation in dimension. Further, in some cases, when there is image distortion in an exposure equipment, alignment error of the element etc. occurs. In the method using the resistance detector element, a real height of the MR element is not directly measured and it is assumed as a major premise that the resistance detector element and the MR element are formed in conformity to design dimensions and design alignment.

Accordingly, if the dimensions of the resistance detector element and the MR element vary as described above or there occurs misalignment in these elements, these variation and misalignment all give rise to measurement errors and finally the variation in the height of the MR element in the lapping process.

Summary of The Invention

The object of the present invention, in a method for in-process measuring the height of the MR element wherein the resistance value of the resistance detector element is measured in the lapping process and the value is converted to the height of the MR element, is to provide both a method for measuring the variation in dimensions and misalignment of the MR element and the resistance element, which become error factors, and an apparatus for the method as well as a method for monitoring a MR element formation process by using the above-described method and apparatus, finding a process trouble, and modifying parameters of film deposition equipment and exposure equipment.

To achieve the above-described object, the method for measuring the dimensions and alignment of the thin film magnetic head according to the present invention is a method

wherein the magnetoresistance effect element and the resistance detector element for monitoring the lapping, both of which are formed on a substrate, are illuminated with light emitted from a light source whose wavelength in the 300 nm or less, preferably in the 200 nm, an image is formed by imaging reflected light from the aforesaid element, the aforesaid image is converted to an image signal through photoconversion, and geometrical information of the above-described magnetoresistance effect element and the above-described resistance detector element for monitoring the lapping is detected from the aforesaid image signal.

Further, in the present invention, the above-described light is prescribed to be light of a wavelength of 248 nm, or that of 266 nm, or that of 213 nm.

Moreover, in the present invention, the above-described geometrical information includes dimensions of the element or alignment error of the element.

Furthermore, in the present invention, the above-described magnetoresistance effect element and the above-described resistance element for monitoring the lapping have a structure wherein the element is covers with end face protection films.

Also, to achieve the above-described object, the method for measuring dimensions and alignment of the thin film magnetic head according to the invention is a method wherein the magnetoresistance effect element and the resistance detector element for monitoring the lapping, both of which are formed on a substrate, are illuminated with light emitted from a light source whose wavelength in the 300 nm or less, preferably being in the 200 nm, reflected light from the element is made to interfere with reference light, interference light thus formed (i.e. a combination of the diffracted light and the reference light) is imaged to form an image, this image is converted to an image signal through photoconversion, and geometrical information of the magnetoresistance effect element and the resistance detector element for monitoring the lapping are detected from this image signal.

Also, to achieve the above-described object, the apparatus for measuring dimensions and alignment of the thin film magnetic head according to the invention comprises:

a light source;

illuminating means for illuminating the magnetoresistance effect element and the resistance detector element for monitoring the lapping, both of which are formed on a substrate, with light emitted from a light source whose

wavelength in the 300 nm or less, preferably being in the 200 nm;

imaging means for imaging reflected light from this element;

image picking up means for converting the image obtained by this imaging means to an image signal; and

geometrical information detecting means for detecting their geometrical information of the magnetoresistance effect element and the resistance detector element for monitoring the lapping.

Also, to achieve the above-described object, the apparatus for measuring dimensions and alignment of the thin film magnetic head according to the invention comprises:

a light source;

illuminating means for illuminating the magnetoresistance effect element and the resistance detector element for monitoring the lapping, which are both formed on a substrate, with light whose wavelength is in the 300 nm or less, preferably being in the 200 nm;

interfering means for making reflected light from the element interfere with reference light;

imaging means for imaging the interference light;

image picking up means for converting an image obtained by this imaging means to an image signal; and

geometrical information detecting means for detecting their geometrical information of the magnetoresistance effect element and the resistance detector element for monitoring the lapping.

Brief Description of The Drawings

FIG. 1 is a view showing a situation of formation of row bars on a wafer.

FIG. 2 is a view showing a situation of formation of the MR elements and the resistance detector elements on the row bar as well as a lapping process thereof.

FIG. 3 is a diagram showing a constitution of a dimension/alignment measuring apparatus for MR and ELG (an apparatus for measuring dimensions and alignment of the MR element and the resistance detector element) according to a first embodiment of the present invention.

FIG. 4 is a graph showing a characteristic of spectral transmittance of a dichroic mirror.

FIG. 5 is a view showing the MR element to be measured and its electrode part.

FIG. 6 is a view showing a cross-sectional structure of the MR element.

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FIG. 5 is a view showing the MR element to be measured and its electrode part.

FIG. 6 is a view showing a cross-sectional structure of the MR element.

FIG. 7 is a view showing the resistance detector element to be measured and its electrode part.

FIG. 8 is a diagram showing an image signal along a height direction of the MR element and its differential waveform.

FIG. 9 is a diagram showing an example of mensuration of relative alignment error of the MR element and that of the resistance detector element.

FIG. 10 is a diagram showing results of measurement of the height of the MR element and that of the resistance detector element for a row bar on a wafer.

FIG. 11 is a diagram showing results of measurement of alignment of the MR elements and that of the resistance detector elements.

FIG. 12 is a schematic diagram showing a constitution of a dimension/alignment measuring apparatus for MR and ELG according to a second embodiment of the present invention.

FIG. 13 is a schematic diagram showing a constitution of a dimension/alignment measuring apparatus for MR and ELG according to a third embodiment of the present invention.

FIG. 14 is a schematic diagram showing details of a measurement optical system according to the third embodiment of the present invention.

FIG. 15 is a schematic diagram showing a phase modulation element according to the third embodiment of the present invention.

FIG. 16 is a schematic diagram showing a constitution of a dimension/alignment measuring apparatus for MR and ELG according to a forth embodiment of the present invention.

Description of The Preferred Embodiments

Hereafter, embodiments according to the present invention are described with reference to the drawings.

First, prior to description of embodiments according to the present invention, sources that cause the variation in dimensions of the MR element in the lapping process will be described.

FIG. 1 and FIG. 2 are a view showing the formation process of the MR elements and the resistance detector elements and a view showing the lapping process of these elements, respectively. As shown in FIG. 2, a plurality of the MR elements 3 and the resistance detector elements 4, which are located at the both side of each MR element so that the MR elements are placed therebetween, are formed in a band by a thin film process whose typical techniques are sputtering, exposure, ion-milling, etc. A plurality of the elements formed is separated from a wafer 1, being cut off

in a band. This band is called a row bar 2. Within one row bar 2, for example, 30 pieces of the MR elements 3 and 31 pieces of the resistance detector elements 4 are formed. In an example shown in FIG. 1, four pieces of the row bars 2 comprises one unit U and each elements are formed by gang exposure (exposed as a group).

As shown in FIG. 2(a), by lapping a cut-off row bar 2 from the direction of an arrow indicated in the figure, 30 pieces of the MR elements 3 are gang lapped so that the MR elements 3 are exposed in the floating plane 80 and all MR elements 3 are controlled to have the height h_{MR} of a prescribed dimension, and further the floating plane 80 is processed in a prescribed shape with a prescribed roughness.

Here, since reproduced output varies depending on the height h_{MR} of the MR element, if the heights of the MR elements varies, there occurs a problem that the reproduced output varies or that a prescribed reproduced output cannot be attained, hence the MR element becoming a defective. Therefore, in order to suppress the variation in reproduced output of the MR element and also to attain a high yield, it is necessary to measure the height of the MR element h_{MR} in the lapping process and control the amount of lapping with a high degree of accuracy for all MR elements.

In order to implement this requirement, resistance detector elements (ELG) 4 are used that are formed in the vicinity of the MR elements 3 by an identical process. That is, in the FIG. 2(a), current is supplied from an electrode 5 of each resistance detector element 4, the change of the resistance value by lapping is measured for each resistance detector element, the height of the MR element h_{MR} is calculated from the resistance value, and then the row bar 2 is bent and a lapping weight is controlled as is shown in FIG. 2(b) so that the resistance values, namely the heights of the MR elements h_{MR}, become uniform and hence an alignment curve 7 defined by each position 6 of each resistance detector element 4 becomes a straight line.

The major premise underlying this method is that dimensional error and alignment error among the MR elements 3, dimensional error and alignment error among the resistance detector elements 4, and dimensional error and alignment error among both of the MR elements 3 and the resistance detector elements 4 are all within about one tenth of a target dimensional accuracy (for example ± 0.2~0.15 μm), namely within about 20 to 15 nm.

The resistance detector elements 4 and the MR elements 3 are formed by an identical process including techniques such as sputtering, exposure, ion-milling, etc. using an

identical exposure mask. In case, for example, there are image distortion and/or illuminance unevenness in a exposure equipment or unevenness in resist coating etc. in the exposure process, the MR elements 3 become out of alignment to the alignment curve 7 defined by the resistance detector elements 4 as shown in FIG. 2(a), or dimensional error of the element height among the MR elements 3 or the resistance detector elements 4 occur as shown in the same figure.

If lapping is performed in this situation so that the resistance values of resistance detector elements 4 become uniform, as is shown in FIG. 2(b), by bending the row bar and adjusting the lapping weight (so that the alignment curve 7 becomes a straight line), the heights of the MR elements 3 h_{MR} vary largely after lapping as is shown in FIG. 2(c).

In view of this, the present invention intends to monitor the MR element formation process, find nonconformity in its early stage, and modify process parameters by measuring directly the variation in dimensions of the MR elements and that of the resistance detector elements, which are error factors in the above-described lapping method, and alignment error of the both elements just after the MR elements 3 and the resistance detector elements 4 are formed on the wafer 1. Hereinafter, embodiments according to the present invention will be described in detail with reference to FIG. 3 to FIG. 16.

First, a first embodiment according to the present invention will be described with reference to FIG. 3 to FIG. 11.

FIG. 5 is a view showing the MR element 3 to be measured and electrodes 49a and 49b located at both sides of the MR elements 3. FIG. 6(a) is a view showings a structure of a cross section taken along a-a in FIG. 5; FIG. 6(b) is a view showings a structure of a cross section taken along b-b in FIG. 5. Further, FIG. 7 is a view showing the resistance detector element 4 which is another component to be measured and its electrode part 5.

When the surface recording density exceeds 10 Gbit/inch^2, narrowing of the track width going further, the track width W_t of the MR element 3 shown in FIG. 5 decreases to 0.5 μm or less and it is expected that the precision of the element height h_{MR} is required to be about $\pm$0.15 μm or so.

Based on a principle of the above-described lapping method, in order to ensure this accuracy, it is necessary to control the accuracy of the height h_{MR}, the track width

W_T of the MR element in FIG. 5, the height of the resistance detector element 4 h_{RLG} in FIG. 7, and also alignment error among the MR elements, alignment error among the resistance detector elements, and relative alignment error between both elements to be within ± 0.15 μm or so. Therefore, measurement accuracy that is required of the present invention is the one which enables measurement of the variation in dimensions and alignment error within this value, ±0.15 μm or so.

Hereupon, in case normal visible light, for example light of a wavelength of 0.5 μm or so, is employed, provided that a numerical aperture (NA) of an optical system is 0.9, the theoretical resolution is calculated to be approximately 0.34 μm (i.e. 0.61 (wavelength/NA)) and hence the above-described track width W_T=0.5 μm reaches almost the resolution limit. It is extremely difficult to measure with a high degree of accuracy the height of the MR element h_{MR} and the height of the resistance detector element h_{RLG} which have the variation of ±0.15 μm, needless to say to measure the track width W_T accurately, from images whose feature sizes are in the vicinity of such resolution limit. Measuring the variation in dimensions and alignment error of ± 0.15 μm requires almost the same resolution in measurement.

By the way, as shown in FIG. 6 (a), end faces 3a and 3b of the MR element 3 in a direction of electrodes are covered with electrodes 49a and 49b, making a construction wherein the end faces 3a and 3b do not expose to the atmospheric air as it is. On the other hand, as shown in FIG. 6(b), end faces 3c and 3d of the MR element in a direction of the height h_{MR} are generally covered with transparent ceramic thin films 51a and 51b having a thickness of tens of nanometers which serve as end face protection films because otherwise the end faces 3c and 3d in situ are exposed to the atmospheric air and likely to suffer corrosion.

In FIG. 5, broken lines 50a and 50b show boundaries of these transparent end face protection films. If, for example, SEM (Scanning Electron Microscope) or AFM (Atomic Force Microscope) are used to obtain the above-described resolution of 0.15 μm or so, detected signal obtainable is the one that catches only surface profile of the end face protection film and cannot catch underlying end faces 3c and 3d.

In view of such restriction given by the target to be measured, the present invention has been created. FIG. 3 is a diagram showing a constitution of a dimension and alignment measurement apparatus for the MR elements and resistance detector elements according to the present invention (hereinafter abbreviated as a dimension/alignment measurement apparatus for MR and ELG).

This apparatus is composed of a measurement optical system 101, an automatic focusing system 201, an image signal processing and controlling system 301, and a stage system 401.

A major feature of this apparatus is that DUV (Deep Ultraviolet) light of a wavelength of 248 nm and a DUV matching objective lens with a NA of 0.9 are employed to detect an element pattern for the purpose of implementing image mensuration through the medium of the end face protection films described above and enabling measurement of the variation in dimensions and alignment error of ± 0.15 μm or so. In this case, the theoretical resolution becomes 0.17 μm, and the variation in dimensions of the height of the MR element h_R and that of the resistance detector element h_{EL}, both of which being ±0.15 μm or so, as well as the above described track width W_t of 0.5 μm or so, can be measured and mensuration of alignment error of the MR elements and the resistance detector elements can also be performed.

The stage system 401 is composed of high-precision X-stage 28x and Y-stage 28y whose straightness is 10 nm or so in the range of the length of the row bar, for example 50 mm, θ stage 29, and a high-precision Z-stage 30 whose straightness is 10 nm or so in the range of its stroke of 50 μm. A wafer 1 is mounted on a vacuum chuck (not shown in the figure) on the Z-stage 30. After a row bar is mounted, θ stage 29 is rotationally adjusted so that a direction of the row bar (being parallel to the plane of the figure) is parallel to a scanning direction of the X-stage 28x (being parallel to the plane of the figure).

In the measurement optical system 101, an element area on the wafer 1 is epi-illuminated with DUV light 22 of a wavelength of 243 nm emitted from the DUV light source 21 through a DUV matching relay lens 23 and a DUV matching objective lens 26 with a NA of 0.9. By the way, a beam splitter 24 is for separating illumination light and detected light, and a dichroic mirror 25 is for separating the DUV light 22 and laser light 33 of a wavelength of 750 nm for automatic focusing. Reflected light from the element

area on the wafer 1 is imaged onto a CCD solid image pickup element 38 through the DUV matching objective lens 26 and DUV imaging lens 37. The pixel size of the CCD solid image pickup element 38 is chosen to be about 10 nm on the wafer considering that mensuration of dimensions and alignment are to be performed with the accuracy of ± 0.15 μm or so.

In the image signal processing and controlling system 301, an image signal from the CCD solid image pickup element 38 is converted to digital signal with a AD converter 39 and then fed into a computer 40. The computer 40 control the X-stage 28x and the Y-stage 28y in a step-and-repeat scanning manner through a stage driver 31 based on the design alignment data of the MR element and the resistance detector element which are stored in a memory 43 beforehand. Along the row bar (area of the row bar on the wafer 1) as shown in FIG. 2, the computer 40 repeats a cycle : translating the X-stage 28x → halting → picking up an image of the MR element → translating → halting → picking up an image of the resistance detector element → translating → halting → ······. When picking up images is completed for all elements within one row bar, the computer 40 makes the Y-stage 28y move in a position of another row bar and makes the X-stage 28x translate to perform the measurement and repeats it.

The depth of focus for the measurement optical system 101 is calculated to be ± 0.15 μm based on the wavelength of 248 nm and the NA of 0.9 of the DUV matching objective lens 26, and therefore it is dispensable to perform high-precision focusing in picking up images.

In view of this, the automatic focusing system 201 performs this focusing in the present embodiment. A collimated light beam 33 of a wavelength of 780 nm emitted from a semiconductor laser 32 is reflected by the dichroic mirror 25, and made to enter a peripheral portion of a pupil of the DUV matching objective lens 26 and then to illuminate the wafer 1 obliquely from above. The reflected light enters the objective lens 26 obliquely, being transformed into a collimated light beam 48, and enters a two-division photodiode sensor 34.

The two-division photodiode sensor 34 comprises two photodetector parts 34a and 34b, whose output signals from both photodetector parts 34a and 34b are fed into a difference circuit 35, and a differential signal from the difference circuit 35 is sent to the computer 40. When an element pattern to be measured on the wafer 1 is in an in-focus condition to the CCD solid image pickup element 38,

a position of the sensor 34 is fine-tuned beforehand so that this differential signal is set to be zero.

As shown in FIG. 3, when the stage height or the height of an element pattern to be measured varies, a position of the reflected light beam 48 from the wafer 1 changes, which causes output from the difference circuit 35 to increase or decrease. The Z-stage 30 is fine-tuned in response to a control signal from the computer 40 so that this differential output is constantly maintained to be zero, and thereby an in-focus condition is held.

FIG. 4 is a graph showing a characteristic of spectral transmittance of a dichroic mirror 25. The dichroic mirror 25 transmits 90 % or more of the DUV light of a wavelength of 248 nm used for image mensuration and also transmits 95% or so of the laser light used for automatic focusing. Further, this measurement optical system 101 is constructed using a double-telecentric optical system, which generates smaller magnification error in response to a small amount of shift in a focal position. By the way, an automatic focusing system may be a system which calculates the contrast of a pattern, a detected image itself, and fine-tunes the Z-stage 30 so that the contrast is maximized.

The computer 40 performs mensuration of each dimension from a detected image during translating the stage to a neighboring element after picking up the element image. The above-described FIG. 5 is a view showing the detected image 47 of the MR element 3. An image signal 45 in a direction of the b-b part, namely a direction of the element height h_{MR}, is shown in FIG. 8(a). If an operation of differentiation is performed on this signal, a differential waveform 46 shown in FIG. 8(b) can be obtained. The height of the MR element h_{MR} can be obtained by finding zero crossing positions h_1 and h_2 of the differential waveform 46 and calculating $|h_1 - h_2|$. The track width W_t in FIG. 5 and the height of the resistance detector element h_{ELG} in FIG. 7 can be obtained similarly.

FIG. 9 is a diagram showing an example of mensuration of relative alignment error of the MR elements and the resistance detector elements on the basis of the straightness of the X-stage 28x, namely using its lucus in a direction of scanning as a reference. From a detected image 81 on the left side in the figure, the distance S_{ELG} from a lower edge part 81a of the image 81 to an upper edge part 85a of the resistance detector element 85 is measured, and then the X-stage 28x is translated and an image 82 of the MR element 90 is detected. Similarly, the distance S_{MR} from a lower edge part 82a of the image 82 to an upper part 90a of the MR element 90 is measured, and then the X-stage

28x is again translated and an image 83 of the resistance detector element 86 is detected. Similarly, the distance S_{ELG} from a lower edge part 83a of the image 83 to an upper part 86a of the resistance detector element 86 is measured.

The computer 40 repeats the above-described measurement for the MR elements of one row bar. That is, in this measurement, the lower edge of the detected image is used as a reference and a distance from the lower edge to an upper edge of each element is taken as an alignment measured value.

FIG. 10 is a diagram showing results of measurement of the heights of the MR elements h_{MR} and those of the resistance detector elements h_{ELG} for the row bar 2a on the wafer 1 shown in FIG.1. Solid circles 8a represent the heights of the MR elements h_{MR} and solid squares 9a represent the heights of the resistance detector elements h_{ELG}. A broken line 10a represents a design value of 4.7 μm and the figure indicates that measured values for each elements exceed the design value, respectively. Further, two large wave undulations for the heights of the MR elements h_{MR} are considered to be caused by illuminance unevenness in the exposure equipment.

FIG. 11 is a diagram showing results of measurement of alignment of the MR elements and the resistance detector elements for the row bar 2a on the wafer 1 shown in FIG. 1 similarly. Solid circles 8b represent the alignment of the MR elements and solid squares 9b represent the alignment of the resistance detector elements. In the figure, an average value of the above-described alignment measured values of the resistance detector elements is set to be zero, as shown by a broken line 10b, and the relative values of the alignment measured values to the average value are plotted to show the alignment of the MR elements. Wave undulations recognized for both elements are considered to be caused by illuminance unevenness and image distortion in the exposure equipment.

In the present embodiment, measurement results shown in FIG. 10 and FIG. 11, the variation in dimensions of the elements in an exposure area or in a whole wafer, or two dimensional distribution of alignment error can be displayed on a display 41. When the variation in dimensions or alignment error exceeds a prescribed value, the following measures can be taken: a row bar or wafer in concern is stopped at the process so as not to flow into a next process; and maintenance instructions are issued for an exposure equipment, a resist coater, a film deposition equipment, or the like, which are all used for element formation, in order

to find nonconformity at its early stage, to modify process parameters to reduce illuminance unevenness, or to fine-tune film thickness. By taking such measures, it is substantially possible to apply the measurement results in managing and controlling the process. Also, measured data are stored in a memory 41, and therefore these data can also be utilized to monitor the variation in dimensions and the variation in alignment error in a long period.

Hereupon, in the present embodiment, a combination of a mercury-xenon lamp and an interference filter with a center transmission wavelength of 248 nm is chosen to be the DUV light source. Alternatively, a fourth harmonic wave of a semiconductor laser pumped YAG laser, namely the 266 nm light, or its fifth harmonic, namely the 213 nm light, or its third harmonic, namely 355 nm light may be used. Alternatively, an ArF excimer laser (wavelength 193 nm) and a KrF excimer laser (wavelength 248nm) may also be used. Also, the I line of a mercury lamp (wavelength 365 nm) may be used.

Further, in the present embodiment, a scanning lucus of the X stage 28x is persistently chosen to be a basis for mensuration of element alignment. Alternatively, to improve further the accuracy of the measurement, it is also possible to monitor constantly the displacement of the stage with a laser length measuring machine, a capacitive sensor, or etc. which is temperature controlled and correct a reference position of detected images by that amount of displacement.

Further, in case the laser length measuring machine is used, relative displacement between the measurement optical system 101 and the wafer 1 can be monitored constantly by mounting both a measurement mirror on a vacuum chuck and a reference mirror on the objective lens 26, and hence higher-precision mensuration of alignment can be implemented. Furthermore, it is also possible that the straightness profile of the X-stage 28x was measured beforehand and, based on the measured data, measured images are corrected.

As described in the foregoing, mensuration of various dimensions of the MR element whose track width W_r is 0.5 μm or less and the resistance detector elements as well as alignment error among these elements can be performed even when the MR elements are covered with end face protection films, and consequently a situation of the element formation process can be in-process monitored. By virtue of this, it can be possible that problems in the process are found at its early stage, the process parameters are modified, and

thereby defective products are reduced in number and the yield is improved. In addition, in controlling the lapping weight in the lapping process, feedforward control lapping can also be realized, wherein the amount of weight is corrected based on measured data of dimensions and alignment.

Next, a second embodiment according to the present invention will be described with reference to FIG. 12. FIG. 12 is a schematic diagram showing a constitution of a dimension/alignment measuring apparatus for MR and ELG according to a second embodiment of the present invention.

This apparatus is composed of a measurement optical system 102, the automatic focusing system 201, the image signal processing and controlling system 301, and the stage system 401. Large difference of the present embodiment from the first embodiment is that the measurement optical system 102 is constructed by mounting oblique illumination systems for detecting an image 60a and 60b (parallel to a plane of the figure) and 60c and 60d (normal to the plane, not shown in the figure) on the measurement optical system 101 of the first embodiment. Constructions and features of other components, that is, the automatic focusing system 201, the image processing and controlling system 301, and the stage system 401 are the same as in the first embodiments and therefore description for these components will be omitted.

Each of the oblique illumination systems 60a, 60b, 60c, and 60d is composed of a fourth harmonic generator of a semiconductor laser-pumped YAG laser and a beam forming optical system. The oblique illumination systems 60a, 60b, 60c, and 60d emit light beams of a wavelength of 266 nm 61a, 61b (parallel to the plane of the figure) and 61c, 61d (normal to the plane, not shown in the figure), and made to illuminate the element area on the wafer 1 obliquely from above in four directions. For example, the end faces 3c and 3d in an element height direction of the MR element on the wafer 1 shown in FIG. 6(b) are illuminated obliquely from above by the oblique illumination systems 60c and 60d, and scattered light from the stepped regions is imaged onto the CCD solid image pickup element 38 through the DUV matching objective lens 26 and the DUV imaging lens 37. Processing after this process is the same as in the first embodiment.

According to the present embodiment, not only the same effects as those of the first embodiment can be obtained, but also an effect can be produced that high-precision mensuration of dimensions and alignment of the MR elements is performed by detecting the scattered light from the stepped regions which are illuminated obliquely from above even when the MR elements and the resistance detector

elements come to have a pattern step whose height is of the order of 10 nm as a result of a trend of reduction in thickness regarding these elements. By the way, the epi-illumination system is still utilized in detecting an alignment pattern for rotation adjustment of a wafer and in performing mensuration of an element pattern having a relatively large step. Further, in the present embodiment, a scanning lucus of the X stage 28x is persistently chosen to be a basis for mensuration of element alignment. Alternatively, to improve further the accuracy of the measurement, it is also possible to monitor the displacement of the stage with a laser length measuring machine which is temperature controlled and correct a reference position of detected images by that amount of displacement.

Next, a third embodiment according to the present invention will be described with reference to FIG. 13 to FIG. 15. FIG. 13 is a schematic diagram showing a constitution of a dimension/alignment measuring apparatus for MR and ELG according to the third embodiment of the present invention.

This apparatus is composed of a measurement optical system 103, the automatic focusing system 201, the image signal processing and controlling system 301, and the stage system 401. Large difference of the present embodiments from the first embodiment is that the measurement system 103 is constructed as a phase difference detection system by adding a phase modulation element for detecting phase difference 62 in a detected light path. Constructions and features of other components, that is, the automatic focusing system 201, the image signal processing and controlling system 301, and the stage system 401 are the same as in the first embodiment and therefore description for these components will be omitted.

A detail of the measurement optical system 103 is schematically shown in FIG. 14. DUV light 64 of a wavelength of 248 nm emitted from the DUV light source 21 is collimated by the DUV matching relay lens 23 and the DUV matching objective lens 26 of a NA of 0.9 and made to epi-illuminate the element area on the wafer 1. The beam splitter 24 is for separating the illumination light and the detected light. A phase modulation element 62 is disposed at a focal position of the objective lens 26 on the image side.

As shown in FIG. 15, the phase modulation element 62 is composed of an area for transmitting DUV light 68 and a quarter wavelength plate 63 in the central part thereof. Of reflected light from the element area on the wafer 1, directly reflected light 69 from the whole portion of the element area is focused on a focal point on the image side

through the DVD matching objective lens 26 and transformed into light 67 with a retarded phase by a quarter wavelength because the directly reflected light 69 passes through this quarter wavelength plate 63.

On the other hand, diffracted light 66a and 66b which pass though the protection films 51a and 51b and then diffracted by element stepped regions 3c and 3d pass though the transmission area 68 of the phase modulation element 61. This transmitted light 66 interferes with the directly reflected light 67 from the whole portion of the element area with a retarded phase by a quarter wavelength, so that the contrast of a detected image of the element is enhanced through this interference effect. That is, the directly reflected light 67 from the whole portion of the element area, being used as reference light, is made to interfere with the diffracted light 65a and 65b from the element stepped region. An image of this interference light is picked up by a CCD solid image pickup element 38. Processing after the image pickup by the CCD solid image pickup element 38 is identical to that described in the first embodiment.

According to the present embodiment, not only the same effect as that of the first embodiment can be attained, but also a high-contrast image can be detected and thereby high-precision mensuration of dimensions and alignment can be achieved because a phase difference at a minute step can be detected as the variation in strength of the interference light by the use of light interference even when there is a trend of reduction in the thickness of the MR elements and the resistance detector elements, reaching a pattern step of the order of 10 nm. By the way, in the present embodiment, a scanning lucus of the X stage 28x is persistently chosen to be a basis for mensuration of element alignment. Alternatively, to improve further the accuracy of the measurement, it is also possible to monitor the displacement of the stage with a laser length measuring machine and correct a reference position of detected images by that amount of displacement.

Next, a forth embodiment of the present invention will be described with reference to FIG. 16. FIG. 16 is a view showing a construction of a dimension/alignment measurement apparatus for MR and ELG according to the forth embodiment of the present invention.

This apparatus is composed of a measurement optical system 104, the automatic focusing system 201, the image signal processing and controlling system 301, and the stage control system 401. Large difference of the present embodiment from the first embodiment is that the measurement optical system 104 is constructed so as to form the

Twyman-Green interferometer. Constructions and their functions of other components, that is, the automatic focusing system 201, the image signal processing and controlling system 301, and the stage control system 401 are much the same as in the first embodiment and therefore description for these descriptions will be omitted.

DUV light 22 of a wavelength of 248 nm emitted from the DUV light source 21 is collimated by the DUV matching relay lens 23 and the DUV matching objective lens 26 having a NA of 0.9, which epi-illuiminates the element area on the wafer 1. At the same time, the light 70 passing through the beam splitter 24 is collimated by the DUV matching lens 26' similarly, and made to illuminate the reference mirror 71. The reflected light form the element area on the wafer1 and the reflected light from the reference mirror 71 retrace their identical light paths, respectively, and are combined to interfere with each other. This interference light 73 is imaged onto a CCD solid pickup element 38 through the DUV imaging lens 37. Process after this step is the same as in the first embodiment.

Also in the present embodiment, the phase difference generated at the element stepped region is transformed into the variation in the strength of the interference light and thereby a high-contrast image can be detected as is the case with the third embodiment. The angle of elevation and a direction of the optical axis of the reference mirror 71 are fine-tuned by driving an actuator 72 in response to a signal from the computer 40 so as to optimize interference effect and hence obtain a high-contrast interference image.

In the present embodiment, the DUV light source is chosen to be a combination of a mercury-xenon lamp and an interference filter having a transmission center wavelength of 248 nm. Alternatively, a forth harmonic of a semiconductor laser-pumped YAG laser, namely the 248 nm light, may be used. By the way, in the present embodiment, a scanning lucus of the X stage 28x is persistently chosen to be a basis for mensuration of element alignment. Alternatively, to improve further the accuracy of the measurement, it is also possible to monitor the displacement of the stage with a laser length measuring machine and correct a reference position of detected images by that amount of displacement.

According to the present embodiment, not only the same effect as those of the first embodiment can be attained, but also a high-contrast image can be detected and thereby high-precision mensuration of dimensions and alignment can be achieved because a phase difference at a minute step can be detected as the variation in the strength of the

interference light by means of light interference even when there is a steady trend of reduction in the thickness of the MR element and the resistance detector element, reaching a pattern step of the order of 10 nm, as is the cases of the second and third embodiments.

Also, the DUV light is not required to be monochromatic light, and may be white light having a certain width of wavelengths instead. In such a case, sharp interference fringes can be obtained by adjusting the reference mirror 71 along the direction of the optical axis so that an optical path length from the beam splitter 24 to the wafer 1 and that from the beam splitter 24 to the reference mirror 71 become identical with each other. By adjusting the Z-stage 30, sharp interference fringes of the pattern can be obtained both for a top part and for a bottom part. The step position in the pattern can be found from change points of the interference fringes.

Furthermore, in the four embodiments described above, the elements to be measured are all MR elements. However, elements to be measured according to the present inventions should not be limited within these elements; it goes without saying that the present invention can be also applicable to GMR (giant magneto-resistive) elements. Moreover, the present invention is not limited to be applied only to thin film magnetic heads because of its fundamental configuration, but can be also applicable to measurement of dimensions and alignment of plural semiconductor element patterns and also to measurement of the accuracy of superposition of patterns in exposing a substrate.

As described in the foregoing, according to the present invention, the following effects are obtained: an effect that high-precision mensuration of a minute MR element having a track width W_T of 0.5 μm or less and a resistance detector element can be performed to find their various dimensions and alignment error even when end face protection films are provided: and an effect that a situation in the element formation process can be in-process monitored. Also, an effect is achieved that occurrence of defective elements can be reduced and hence the yield can be improved through early finding of process nonconformity and subsequent modification of process parameters which are realized by the above-described effects. Also, an effect is attained that a feedforward control lapping can be realized wherein a lapping weight is corrected based on measured data of dimensions and alignment in controlling the lapping weight in the lapping process.